**Table 6-1: Fixed Service System Parameters Used for Example A**

| Parameter[12] | Units |
|---|---|
| Waveform Description | Assume MSS interference power is fully contained within the occupied BW of the FS receiver |
| Latitude/Longitude for XMT/RCV antennas | XMT (lat: 30.35944 deg; long: -103.5511 deg)<br>RCV: (lat: 30.35972 deg; long: -103.6475 deg) |
| Height above sea-level for XMT/RCV antennas | XMT: 12.86 m<br>RCV: 8.57 m |
| Path Length | 9.27 km |
| Frequency | 2.1684 GHz |
| FS Receiver Reference Bandwidth | 1 MHz |
| Azimuth of RCV antenna | 90.2 deg |
| Receive antenna gain pattern | 6-ft dish; use ITU-R F.1245 for antenna gain roll-off pattern |
| Noise floor at input of FS receiver | -135.1 dBW |
| Total RCV losses (other than propagation) | 2 dB |
| Theoretical Received Signal Level (RSL) at Input to Receiver[13] | -33.7 dBm |
| Receiver Threshold ($R_t$) | -78.1 dBm |
| Terrain Designator | Mountains |
| Geoclimatic factor, K | $2x10^{-6}$ (assumes $C_0$=10.5, $C_{lat}$=0, $C_{long}$=-3, and $p_L$=20; see ITU-R P.530-7) |
| System Length (i.e., route length) | 9.27 km (i.e., single path system) |
| Number of Hops | 1 |
| Pre-Emphasis? | Not Applicable (N/A) |
| ATPC? | No |
| RCV Antenna Diversity? | No |

[12] Based upon using ITU-R P.530 for the fading model.

[13] Takes into consideration free space loss.

**Table 6-2: MSS System Parameters Used in Example A**

| Parameter | Units |
|---|---|
| Waveform Description | Constant envelope; Assume MSS interference power is fully contained within the occupied BW of the FS receiver |
| Constellation design | |
| GSO, non-GSO, Elliptical, hybrid, etc. | non-GSO |
| Number of satellites | 10 |
| Number of orbital planes | 2 |
| Number of satellites per orbital plane | 5 |
| Ascending Node separation between planes | 180° +/- 0.5° |
| Phase between in-plane satellite | 72° +/- 0.5° |
| Apogee of each orbital plane | 16,733 km |
| Perigee of each orbital plane | 16,733 km |
| Inclination | 45° |
| Frequency | 2.1684 GHz |
| XMT antenna gain pattern | Isotropic (for simplification) |
| Maximum XMT power | Maximum EIRP = Transmit power (dB) + Maximum Gain (dB) = 34.3 dBW. |
| XMT power model | Constant EIRP at 34.3 dBW |
| Total XMT losses (other than propagation) | 0 dB |

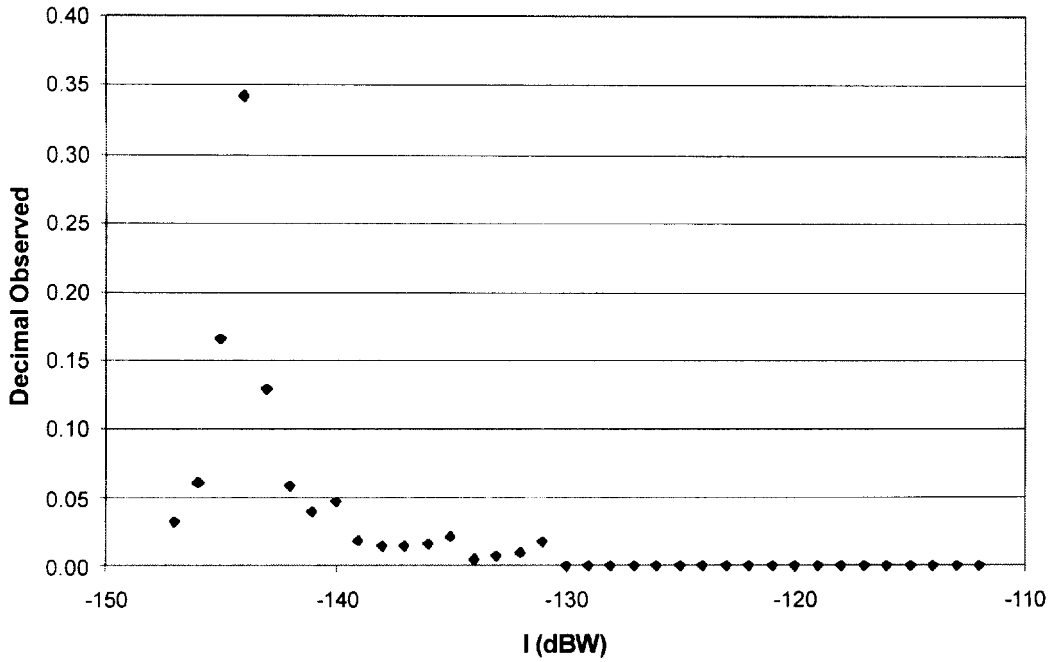



**Figure 6-1: PDF of the MSS Interference Power, I, for Example A**

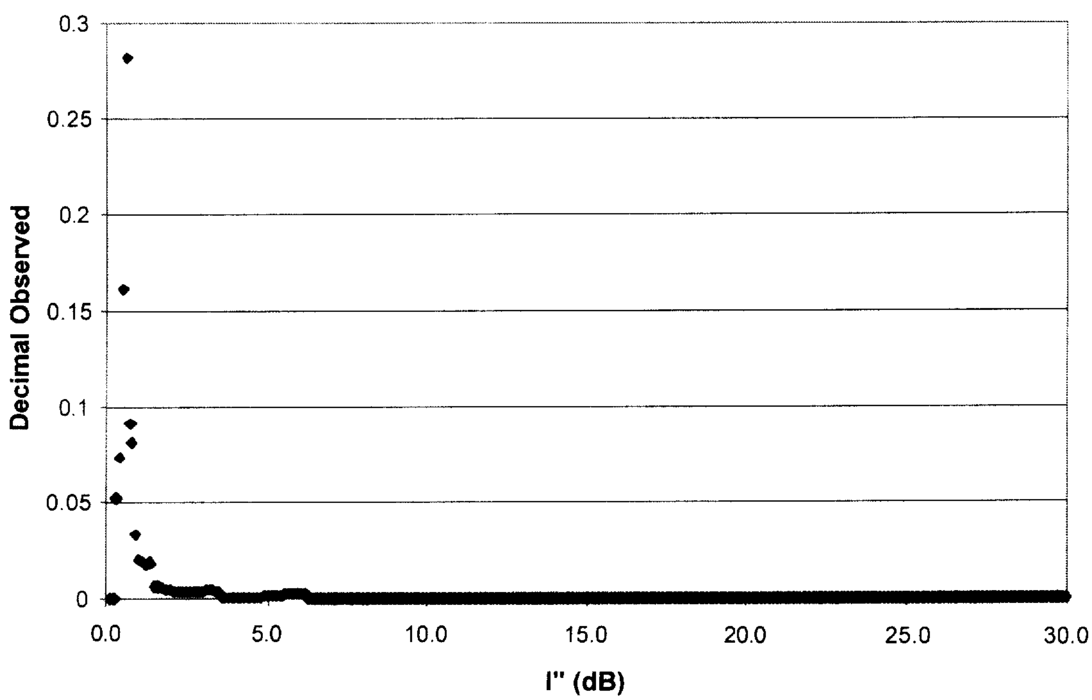



**Figure 6-2: PDF of the Variable I" For Example A**

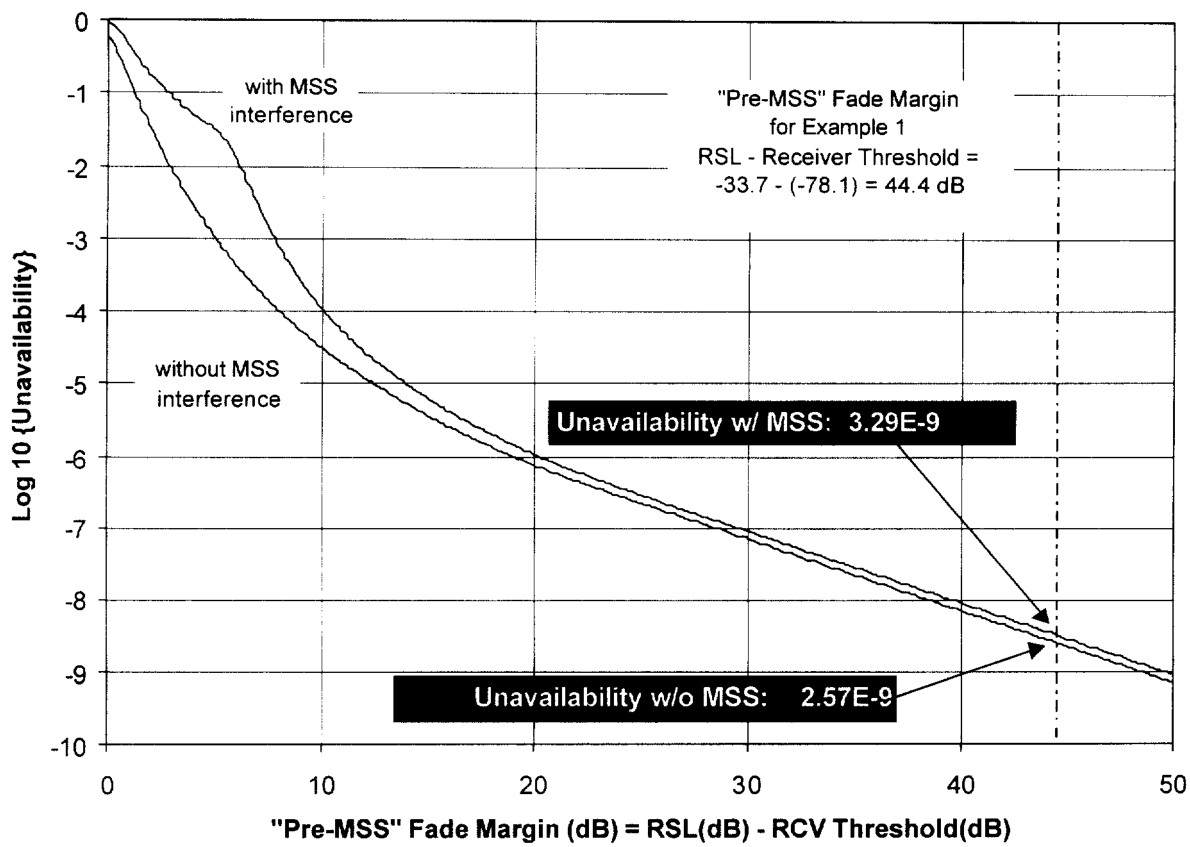



**Figure 6-3: FS Performance Results for Example A**

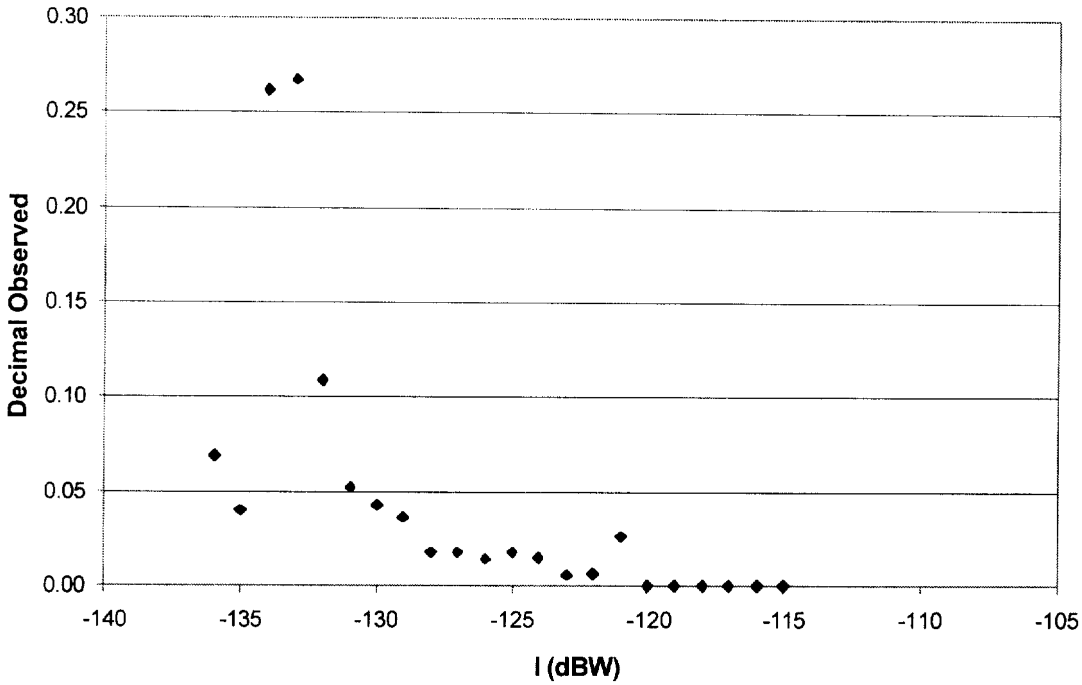



**Figure 6-4: PDF of the MSS Interference Power, I, for Example B**

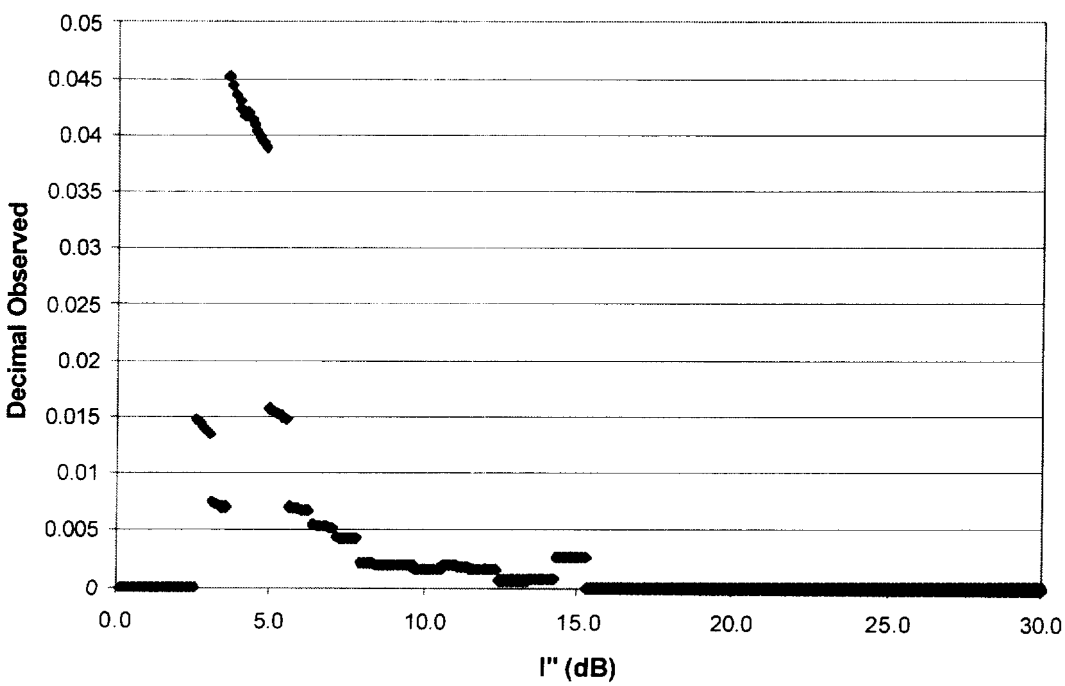



**Figure 6-5: PDF of the Variable I" For Example B**

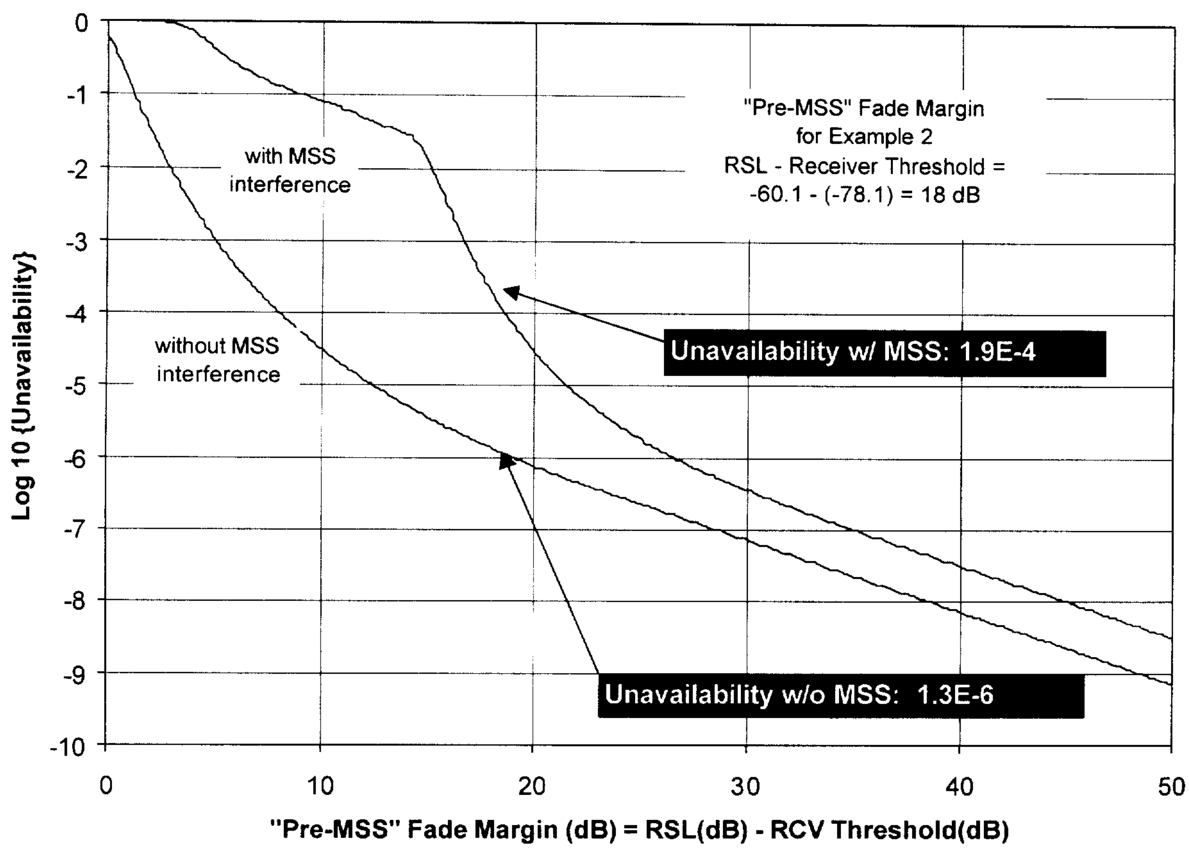



**Figure 6-6: FS Performance Results for Example B**

# 7. Interference Mitigation Techniques

## 7.1 Interference from the Satellite Transmitter to a Victim FS Receiver

This discussionis mainly directed toward reducing or eliminating interference that originates from an MSS satellite (downlink transmitter) and disturbs a FS receiver. This is not intended to be a comprehensive study of possible interference mitigation techniques, which may differ substantially among MSS systems, but it is presented to illustrate candidate means for resolving potential interference problems. MSS systems utilizing the 2.1 GHz frequency band use relatively low power transmitters; consequently, typical interfering signal levels are expected to be lower than the nominal desired signal level of a typical FS receiver. However, even a low level interfering MSS signal may cause threshold degradation and reduce FS path availability to a level below the thresholds specified in this TSB. Table 7-1 summarizes the techniques discussed herein that may mitigate potential interference from MSS satellites to FS stations.

**Table 7-1. Techniques that Might Mitigate Potential Interference to FS Systems**

| TECHNIQUE | STATION(S) INVOLVED | SOURCE OF REDUCTION IN INTERFERENCE |
|---|---|---|
| Antenna Shields and Blinders (7.1.1) | FS receiver system | Increased off-axis antenna discrimination |
| Increase in FS EIRP (7.1.2) | FS transmitter | Reduce line loss in antenna feed |
| Increase in FS Transmission Gain (7.1.2) | FS receiver system | Reduce or eliminate deliberate antenna mis-pointing |
| Relax Interference Criteria (7.1.3) | FS receiver system | Accept interference higher than permissible levels |
| Change frequency (7.1.4) | FS transmitter & receiver | Frequency offset yielding +filter discrimination |
| Improved filtering (7.1.5) | FS receiver system | +Filter discrimination |
| Increased Ant. Gain (7.1.6) | FS transmitter & receiver | +Antenna discrimination |

There are several methods and techniques to reduce or eliminate interfering signal levels without replacing planned or operational hardware. This section will explore some of those methods. Note that some of the techniques may require recoordination with other parties, and that under present FCC Rules, this could also result in a change of the license status from primary to secondary.

### 7.1.1 FS Shields and Antenna Blinders

Specially designed FS antenna shields and blinders can be effective in reducing the received interfering signal power density provided that the attenuation is significant at off-axis angles less than 90° and at elevation angles greater than 10°.
Shields that are made of RF attenuating or blocking material can be placed at the antenna site at off-axis angles less than 90° in order to reduce long-term interfering signal levels. Design considerations should include optimizing the distance from the antenna being shielded, given the benefit of shielding at MSS signal arrival angles greater than 10° in elevation and less than 90° off-axis of the interfering signal as well as the size and shape of the shield. In some cases the use of diffusers may also provide additional signal attenuation by avoiding knife-edge diffraction of the interfering signal over an edge of the shield.

Blinders are basically shields that are mounted directly to an antenna. They are designed to suppress side-lobe gain. The effectiveness of blinders is dependent upon the amount of off-axis angular area above 10° elevation and within 90° off bore-sight that is afforded additional discrimination.

### 7.1.2 Increase in FS System EIRP or Transmission Gain

In designing FS paths, it is sometimes decided that the selected equipment might generate excess desired signal power at the receiver (i.e., more power than is needed to meet performance objectives), and that the power should be reduced for compliance with good engineering practice, prevention of receiver threshold degradation or to facilitate coordination with respect to other FS systems. For example, this could be the case with a short FS transmission path or when the preferred combination of antennas and transmitter power yields a higher EIRP than is necessary for the link budget. In such cases, the FS transmitter system will include an attenuating device, such as a calibrated pad, in order to reduce the EIRP to levels more commensurate with the performance objectives. In these cases, it may be possible to increase the FS transmitter EIRP by simply reducing the attenuator setting in the transmitter system (or eliminating an attenuator altogether) in order to increase the link power margin and acceptable levels of MSS interfering signals. However, increases in FS EIRP may be precluded, in some cases, by FCC Rules governing the maximum allowable EIRP or by prior FS-to-FS coordination agreements.

Alternatively, to reduce the anticipated or experienced effects of threshold degradation to a FS receiver on a path with the potential for excess transmitter power, some designs may use the full FS transmitter power and antenna gain in conjunction with the victim receive antenna being deliberately mis-aligned to direct a side lobe toward the transmitter. In these cases, the transmission gain (sum of antenna gains minus basic transmission loss) can be increased in order to increase the link power margin and acceptable levels of MSS interfering signals. The degree to which these methods can be applied and their effectiveness in resolving cases of potential interference is dependent upon FS system performance tradeoffs with respect to the original motives for reducing the transmitter EIRP or transmission gain.

It should be noted, however, that an increase in FS transmitter EIRP would also increase the likelihood of interference to other FS receive stations previously coordinated. It would also coincidentally increase the potential for interference to MSS MESs operating in close proximity to the FS transmitter when MSS satellite operations commence.

#### 7.1.3 Acceptance of Higher Levels of Interference by FS Systems

The interference thresholds applied in initial interference analyses may be conservative (permit less interference than can be accepted) insofar as they may based on unfavorable assumptions regarding the performance of the FS system--with or without MSS interference. Thus, consideration can be given to accepting higher levels of interfering signals at various percentages of time.

#### 7.1.4 Change Frequency/Retune FS T/R Equipment

If spectrum free of interference problems is available in the 2 GHz frequency range, consideration should be given to the selection of an alternative frequency channel for the problematic FS transmission path. In most cases this would not require a complete replacement of the existing FS equipment, but it may require modification (e.g., reprogramming) of the existing radios.

#### 7.1.5 FS Receiver Filters

In cases where there is frequency separation between at least some of the MSS channels and the FS system occupied spectrum, improved filtering should be considered as a means for reducing potential interference. There are several varieties of tunable filters commercially available at these frequencies. They include varieties that can be easily modified for depth, width and center frequency.

#### 7.1.6 Increase FS Transmitter or Receiver Antenna Gain

Typical FS transmission paths are designed to utilize an antenna system with the smallest possible aperture configuration due to wind-loading and real estate considerations. In some instances, an increase in FS antenna size will sufficiently raise the desired receive signal level to provide a fade margin sufficient to mitigate the effects of an interfering MSS signal.

If a larger receive antenna is considered, it should noted that a larger aperture will produce greater side-lobe suppression. Likewise it should also be noted that increased receive gain will raise the relatively high interfering signal levels proportionate to the increased desired signal level, but the percentages of time associated with these interfering signal levels will be reduced. If the transmitting antenna gain is increased, the EIRP alone will be increased. Both methods should be considered jointly and separately.

### 7.1.7 Interference from a FS Transmitter to a Mobile Earth Station (MES) Receiver

Techniques for mitigating interference from FS stations to an MES can be identified on a case-by-case basis, depending on the nature of the predicted interference and the underlying causative factors. Because the actions of the MES user has substantial influence on the occurrence of interference (e.g., pedestrian or vehicle local position and orientation), high potential probabilities of interference may be acceptable in cases where user mitigation is likely to occur by habit. For example, cellular mobile and vehicular broadcast radio users typically develop operating habits that effectively lessen local performance impairments. In other cases involving higher probabilities of interference, consideration may be given to modification of the interfering FS station or incorporation of frequency assignment to the MES by location techniques within the MSS system. The latter techniques require that an MSS channel be provided free of the local interference (i.e., a channel with sufficient filter discrimination against the problematic, high-level, local FS signals).

## 7.2 Conclusion

In conclusion, when seeking to mitigate interference between MSS and FS systems, one should explore the individual interference case scenario and address the specific actual operating parameters of the transmitters and receivers involved. Consideration should not be limited to a single interference mitigation method, as some of the techniques addressed in this section are complimentary to each other. Selectively combining several techniques may provide sufficient reduction or mitigation of the interfering signals to enable the interfered with system to operate in a satisfactory manner and provide a method of spectrum sharing.

## Annex A: Multipath Fading Model

Several of the methodologies in Section 4 of this TSB require a fading model to predict the cumulative distribution of the probabilities of the received level of the desired signal on a path for all levels of fading, including both the signal enhancement and signal loss due to multipath fading. The only known model that is applicable to the entire range of FS signal fading is contained in Sections 2.3.3 and 2.3.4 of Annex 1 to Recommendation ITU-R P.530-7. The fading predictions are characterized by a single parameter, $q_t$.. The parameter $q_t$, in turn is derived from a prediction of the percent of time that the signal is faded 35 dB below its nominal unfaded level. (In some cases that are identified within the derivation, it is necessary to use the percentage of time for the 25 dB level.)

There are many fade prediction models that could be used to predict FS signal fading of 25 or 35 dB. One of these is the model for small percentages of time provided in section 2.3.1 of Annex 1 to Recommendation ITU-R P.530-7. While many models have been used in the US to predict multipath-fading loss for small percentages of time, the most widely accepted is the one provided in section 4.2.3 of TSB-10F.

The predictions of the time in seconds that fading on a 40-km path exceeds 30 dB has been determined for three paths in the US using both the TIA model and the model for small percentages of time of Recommendation ITU-R P.530-7. Table 1 compares the estimates. Note that the two models produce estimates that differ by as much as a factor of two but have no consistent bias. The sites for these paths were chosen to represent regions where fade occurrence is light, typical and severe. Thus the choice of the TIA model is for convenience rather than to address any identified shortcoming of the ITU model.

**Table 1.** Predicted time in seconds that fading exceeds 30 dB in the worst month.

| Location | Bulletin 10F | Rec. P.530-7 |
|---|---|---|
| Helena, Montana | 110 | 56 |
| Atlanta, Georgia | 441 | 803 |
| New Orleans, Louisiana | 2648 | 2783 |

To use the TSB-10F fading model for the purpose intended here, some minor adjustments are required to bring the model into conformance with the definitions in Recommendation ITU-R P.530-7. To provide the basis for this adjustment, a brief summary of the model for small percentages of time of Recommendation ITU-R P.530-7 is provided in section A.1 of this Annex. A summary of the TSB-10F fading model including the necessary adjustments is provided in section A.2. The results in Table 1, attributed to TSB-10F, were obtained using the adjusted model.

### A.1. Multipath Fading model for small percentages of time of Recommendation ITU-R P.530-7

Section 2.3.1 of Annex 1 of Recommendation ITU-R P.530-7 gives an expression for the percentage of time in an average worst month that the multipath attenuation exceeds a level of $A$ dB. The calculation is valid only for small percentages of the time. The percentage of time that the fade depth is exceeded, which is given there in equation (19), is denoted here as $p_{wspt}$ and given by:

$$p_{wspt} = K\, d^{3.6}\, f^{0.89}\,(1+|\varepsilon_p|)^{-1.4}\times 10^{-A/10} \qquad \% \qquad \text{A-1}$$

where

$K$ is determined by the procedure in equations (4) to (17) of Annex 1 to Rec. ITU-R P.530-7
$d$ is the path length in kilometers,
$f$ is the frequency in GHz,
$\varepsilon_p$ is the path inclination in milliradians, and
$A$ is the fade depth exceeded, in dB.

Sections 2.3.3 and 2.3.4 of Annex 1 of Rec. ITU-R P.530-7 give procedures for predicting the signal attenuation and the signal enhancements, respectively, for all percentages of time in a worst month. The calculations are based on the value of $p_{wspt}$ at a fade depth of 35 dB or 25 dB.

### A.2. Multipath fading model of TIA TSB-10F

In Section 4.2.3 of TSB-10F, equation 4.2-2 gives an expression for the cumulative multipath fading time below level for a non-diversity link, which may be rewritten as:

$$T = rT_o 10^{-A/10} \qquad \text{seconds.} \qquad \text{A-2}$$

where

$T$ = annual outage time in seconds;
$r$ = fade occurrence factor, calculated using equation 4.2-4;
$T_o$ = $(t/50)(8 \times 10^6)$ = length of fade season in seconds;
t = average annual temperature in $^\circ$F ($^\circ$C $\times$ 9/5 + 32); and
$A$ = fade depth exceeded, in dB.

This equation is applicable for path lengths greater than 22.5 km and fade depths greater than 20 dB. It may be converted to the percentage of time in an average worst fading month by assuming that the fading in the average worst fading month is the same as that in the fade season. This gives

$$p_{wTIA} = 100\,T/T_o \qquad \text{A-3}$$

Hence,

$$p_{wTIA} = 100\ r\ 10^{-A/10} \qquad \text{A-4}$$

## A.3. Fading-General Approach Recommended For Purposes of TSB-86

For the purposes of the analyses in section 4 of TSB-86, the multipath fading model of TSB-10F should be used to determine the percentage of time that fading loss exceeds 25 or 35 dB by using equation A-4 of this Annex. This percentage should be used in the development in sections 2.3.2 and 2.3.3 of Annex 1 to Rec. ITU-R P.530-7 to produce a fading model that is valid for all fade levels or, equivalently, for all percentages of time.

## Annex B: Fixed Service Parameters

The actual or predicted receive FS antenna gain patterns should be used whenever possible. In the absence of actual or predicted antenna patterns, the following reference FS antenna pattern (from ITU-R F.1245) is used when analyzing the interference from MSS networks. This is the average radiation pattern side-lobe level.

$$G(\theta) = G_{\max} - 2.5 * 10^{-3} \left(\frac{D}{\lambda}\right)^2 \theta^2 \qquad \text{for } 0° \leq \theta \leq \phi_m$$

$$G(\theta) = 39 - 5 \log\left(\frac{D}{\lambda}\right) - 25 \log \theta \qquad \text{for } \phi_m \leq \theta \leq 48°$$

$$G(\theta) = -3 - 5 \log\left(\frac{D}{\lambda}\right) \qquad \text{for } 48° \leq \theta \leq 180°$$

$$\phi_m = \frac{20}{D/\lambda} \sqrt{G_{\max} - G_1} \quad \text{degrees}$$

$$G_1 = 2 + 15 \log (D/\lambda) \quad \text{dBi}$$

where: $G(\theta)$ is antenna gain at an off-axis angle $\theta$ (in degrees); $G_{max}$ is the antenna gain (dBi); and $D$ is the antenna diameter (meters); and $\lambda$ is the wavelenth (meters).

**Polarization Adjustment**

MSS satellite systems and FS systems usually employ circular and linear polarization respectively. A polarization advantage is applied when the MSS spot beam pointing vector is within the main-lobe region ($0° < \theta < \phi_m$) of the FS antenna. This is accomplished by specifying an equivalent FS antenna gain.

$$G_{eff}(\theta) = 10 \log\left(10^{0.1G(\theta)} + 0.02 \cdot 10^{0.1G_{\max}}\right) - 3$$

where $G(\theta)$ is the value calculated in section 1.0.

## Annex C: MSS Satellite Antenna Patterns

The actual or predicted MSS antenna radiation pattern should be used whenever possible. In the absence of actual or predicted antenna patterns, one the following reference antenna patterns may be used.

### C.1. Report ITU-R S.558

This pattern is for satellite antennas employing circular beams. The equations' coefficients depend upon side lobe level, $L_S$, as being either -20, -25 or -30 dB. The value of $L_s$ determines the start and end of the side lobe, defined by parameters a and b. The values of $L_s$, a and b, depend on the type, which can be one of I, II, or III, as shown in the table below:

| Type | $L_S$ | a | b |
|---|---|---|---|
| I | -20 | 2.58 | 6.32 |
| II | -25 | 2.88 | 6.32 |
| II | -30 | 3.16 | 6.32 |

The patterns are defined as:

$$\psi = \frac{\theta}{\left(\theta_{3dB}/2\right)}$$

Then:

if $\psi \le a$:

then $G_{abs} = G_{\max} \quad 3\psi^2$

if $a < \psi \le b$:

then $G_{abs} = G_{\max} + L_s$

if $b < \psi$:

then $G_{abs} = \max\left[0, G_{\max} + L_s + 20 - 25\log\psi\right]$

### C.2. Appendix 30 Pattern

The equations for satellite antennas specified in ITU Radio Regulations, Appendix 30 are:

when $\theta < 1.45\theta_{3dB}$

$$G_{rel} = -12\left(\frac{\theta}{\theta_{3dB}}\right)^2$$

otherwise:

$$G_{rel} = -\left(22 + 20\log_{10}\left(\frac{\theta}{\theta_{3dB}}\right)\right)$$

Note that $G_{rel}$ can not be less than $-G_{max}$.

## C.3. Appendix 30 Fast Roll-Off Pattern

The equations for the ITU Radio Regulations Appendix 30 so called "fast roll-off" "satellite antennas are:

$$\phi = 05\left(1 - \frac{0.8}{\theta_{3dB}}\right)$$

when $\theta < 05\theta_{3dB}$:

$$G_{rel} = -12\left(\frac{\theta}{\theta_{3dB}}\right)^2$$

else when $\theta < 1.16 + \phi\theta_{3dB}$:

$$G_{rel} = \quad 18.75(\theta \quad \phi\theta_{3dB})^2$$

else when $\theta < 1.45\theta_{3dB}$ :

$$G_{rel} = -25.23$$

otherwise:

$$G_{rel} = -\left(22 + 20\log_{10}\left(\frac{\theta}{\theta_{3dB}}\right)\right)$$

Note that $G_{rel}$ can not be less than $-G_{max}$.

# Annex D: Satellite Traffic Models

## D.1. Introduction

A major factor in the calculation of the interference into FS systems from MSS satellites is the EIRP per spot beam on the satellite. This annex describes two methods to calculate the instantaneous spot beam EIRP for non-CDMA MSS systems; i.e., TDMA MSS Systems (See Recommendation ITU-R M.1143, which contains an approach for CDMA systems that can be considered). The first method is to be used in the precursor analysis process while the second method is more appropriate for the negotiation phase of the frequency coordination.

## D.2. Generic Method

The purpose of the generic method is to provide a relatively simple, somewhat conservative method of simulating the traffic loading of an MSS system, while not being unrealistic. The methodology allows for the simulation of actual characteristics of an MSS system including its frequency re-use capabilities and any inherent frequency assignment constraints. Further, the simulation is constrained in such a way that the maximum number of voice channels that an MSS system can simultaneously transmit, within its prime power design constraints, is not exceeded. Finally, the method also allows for the simulation of self-imposed constraints the MSS operator may wish to place on its own system, such as the turning off of the outer rings of the satellite antenna spot beams that would otherwise provide redundant coverage.

The generic method is outlined in the steps below:

i) Determine the maximum number of spot beams that can possibly transmit simultaneously at the same frequency in the reference bandwidth, and group them into categories. This determination will be dependent on system characteristics such as frequency re-use, frequency block bandwidth and frequency block assignment to the spot beams. If two or more frequency blocks can be assigned to a specific beam type, uniformly distribute the blocks among the beams belonging to that beam type. Create a file containing these various groups for use by the simulation program.

   Example: A spacecraft antenna has a four-cell frequency re-use pattern and eight frequency blocks of 1 MHz each. The beams would be grouped into categories A, B, …, H;

ii) Uniformly distribute the maximum number of TDMA channels that the spacecraft can simultaneously transmit among all spot beams on the spacecraft;

iii) At each time step, one spot beam group (e.g., A or B or C, etc.) is randomly selected. It is assumed that all beams of the same group are transmitting at that time instant on the same frequencies (assuming no additional interference mitigating constraints are present, such as the outer beams turned off);

iv) In recognition of the time-varying nature of the MSS traffic, the total number of voice channels of each satellite spot beam is randomly varied between two defined levels. For each selected spot beam, randomly vary the number of voice channels between the minimum and maximum levels. The voice channels should be assigned to their TDMA channels according to any algorithm relevant to the system.

Notes:

When using a reference bandwidth of 1 MHz, the maximum number of channels per spot beam will be the lesser of:

i) the maximum number of voice channels that can fit into a 1-MHz bandwidth, or
ii) the maximum number of voice channels of the satellite divided by the number of spot beams.

When using a 1-MHz reference bandwidth, the minimum level of traffic is assumed to be ¼ of the maximum number of voice channels as determined above. This minimum traffic level is substantially higher than the actual minimum level, which skews the distribution of traffic levels in a very conservative manner (i.e., leading to over-estimation of interference).

Taken together, the average interference power during the course of the simulation will be 62.5% of the maximum or approximately the maximum level less 2 dB.

## D.3. Detailed Method

The generic method described in Section 2 is based on the EIRP of each beam being selected at random. A more accurate assessment of the level of the MSS signal into the FS could be made by taking into account traffic loading on the satellite.

While the traffic level per beam varies according to demand, certain constraints will limit the EIRP per spot beam such as:

- total loading that can be carried by one particular spot beam;
- total loading that can be carried by one particular satellite.

Traffic models should take into account concerns that traffic levels in a particular spot beam could be higher than the average, while not resulting in extremely unrealistic situations such as a scenario in which all spot beams of all satellites are operating fully loaded.

Two basic methodologies, depending on the multiple access scheme employed with the satellite system, are described below and are used to calculate EIRP per spot beam based on input data.

### D.3.1 Methodology for TDMA MSS System

Input data is defined by dividing the world into equally sized cells in latitude and longitude. Each cell has parameters associated with it that can be used to calculate the level of traffic within that cell at any time during the simulation. These parameters would be supplied by the MSS operators based on predicted demand for their services. The traffic can then be allocated to spot beams, potentially shared between multiple visible satellites, taking into account total traffic allowed per beam and satellite.

### D.3.2 Methodology for CDMA MSS System

The level of traffic in each country is defined as high, medium or low. These parameters would be supplied by the MSS operators based upon predicted demand. The spot beam that covers each country is then loaded with an EIRP based upon this traffic level, taking into account total traffic allowed per beam and satellite.

## D.4. Traffic Methodology for TDMA MSS Systems

Traffic levels are determined from two sources:

- a geographic traffic file, specified as a grid containing traffic levels for each (latitude, longitude) cell, and a busy hour offset;
- a diurnal traffic variation file, containing the variation of the traffic level against time over one day.

As the expected platform for the simulations is a personal computer, a suitably practical size of traffic file is 5 degrees of latitude by 5 degrees of longitude.

The traffic level is calculated as follows:

1) the current simulation time and the station position give the local time. This gives the baseline offset to be used in the diurnal traffic variation file;

2) the traffic file gives the additional offset for this particular cell;

3) the total offset is used to get the percentage of traffic in the cell to use from the diurnal variation file.

For the geographic traffic file, variables are stored as:

- offset in minutes from local time;
- number of carriers active at busiest hour.

For the diurnal traffic variation file, variables are stored as:

- offset in minutes from time zero;
- percentage of busy hour (the scale is from 0 to 100, not 0 to 1).

Once the percentage of traffic has been calculated, it is multiplied by the maximum number of carriers at busiest hour in the traffic file for this cell to get the total number of carriers in the traffic cell for this time step. The number of carriers can be multiplied by the carrier bandwidth to get the bandwidth required for this traffic cell.

The next step is to allocate the traffic for a particular cell to the one or more visible satellites. For each satellite, the traffic is assumed to be allocated to the beam with the footprint nearest the center of the traffic cell, with the highest elevation satellite loaded first.

This approach is based on the principle that the blocking is elevation-angle dependent, and that there is a linear relationship: the probability of non-blocking is proportional to the elevation angle/90°.

Traffic will then be allocated to the visible satellites based on the principle that the higher elevation satellite is selected first.

If e = elevation angle/90°, then:

for satellite 1: $p_1 = e_1$
for satellite 2: $p_2 = (1-e_1)e_2$
for satellite 3: $p_3 = (1-e_1)(1-e_2)e_3$, etc.

The ratio of total traffic allocated to the $n_{th}$ satellite is $T_n = p_n/\Sigma p_i$. If some traffic remains unallocated after application of one of the above algorithms, this traffic will be allocated to other satellites.

## D.5. Traffic Methodology for CDMA MSS Systems

A step-by-step development of the traffic methodology appropriate for CDMA MSS systems has not been included in this edition of TSB-86. It will be included in a future edition.

# Annex E: Determination of the Visibility Statistics of Space Stations Operating in Circular Orbits as Seen by a Terrestrial Station

## E.1. Introduction

In order to develop sharing criteria between low-Earth orbiting satellites and FS systems, it is necessary to determine how often a satellite will be visible in any direction for a particular terrestrial station or position and how strong will be the interference received from it. The purpose of this Annex is to develop the equations necessary to simulate the operation of a low-Earth orbiting satellite and thereby the necessary statistics. The development is sufficiently general that the results can be applied either for a random model or for a time evolutionary model.

Section E.2 of this Annex provides a development of the equations of motion of a satellite, which is in a circular orbit, in an inertial coordinate system. In Section E.3, these equations are transformed to a coordinate system fixed on the Earth. The azimuth and distance of the sub-satellite point from a position on the surface of the Earth are determined in Section E.4. In section E.5, the expressions for the elevation and off-boresight angle of the satellite are developed, and a simple criterion for testing for the visibility of a satellite that is above a particular position on the Earth is given. A right-handed spherical coordinate system is used throughout this development for Earth-centered coordinates with $(r, \theta, \lambda)$ where $r$ is the distance from the origin, $\theta$ is the angular distance from the North Pole, and $\lambda$ is the angle around the Pole.

## E.2. The satellite in the inertial frame

In order to determine the position of the satellite in the inertial frame, its position in the orbital plane must first be determined. For a body in a circular orbit around the Earth this description involves four Keplerian orbital parameters as follows:

$R_S$ : orbital radius, the distance from the centre of the Earth to the satellite

$I$ : inclination angle (rad), the angle between the orbital plane and the Earth's equatorial plane. It is measured from 0to $\pi$ and is less than $\pi/2$ if the satellite is headed eastward as it crosses the equatorial plane from South to North and greater than $\pi/2$ if the satellite is headed westward as it crosses the equatorial plane from South to North

$O_S$ : angular distance (rad) along the equatorial plane from the zero reference to the position of the ascending node, the point where the plane of the satellite crosses the equatorial plane from South to North

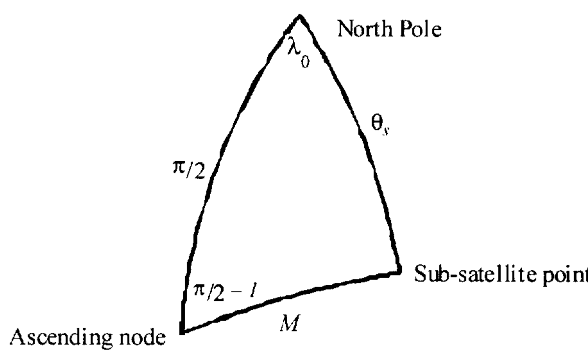
$M$ : mean anomaly (rad), the angular arc in the satellite orbital plane measured from the ascending node to the position of the satellite.

To determine the coordinates of the satellite in the inertial spherical coordinate system, one must first determine the position of the satellite referenced to $\Omega_0$, the angular position or longitude of the ascending node, measured East of the first point of Aries. The position of the sub-satellite point is denoted by $\theta_s$ and $\lambda_0$. These coordinates may be determined by spherical geometry with reference to Figure 1. Applying the law of cosines to the arc $\theta_s$ gives $\cos\theta_s = \sin M \sin I$. Since $\theta$ is defined on the interval $(0, \pi)$:

$$\theta_s = \arccos(\sin M \sin I) \qquad \text{(E-1)}$$

FIGURE 1

**Spherical triangle of satellite in the inertial frame**




Similarly, applying the law of cosines to the arc $M$ gives $\cos M = \sin\theta_s \cos\lambda_0$. Equation (E-2) gives the values of $\lambda_0$ for the entire range $(\theta, 2\pi)$.

$$\lambda_0 = \begin{cases} \arccos(\cos M / \sin\theta_s) & \text{for } \cos I \sin M \geq 0 \\ 2\pi - \arccos(\cos M / \sin\theta_s) & \text{for } \cos I \sin M < 0 \end{cases} \qquad \text{(E-2)}$$

## E.3. Transformation to Earth coordinates

These coordinates may be transformed simply to equivalent Earth coordinates. Since the Earth rotates eastward through $2\pi$ rad in 23 h, 56 min, and 4.09 s, the East longitude of the sub-satellite point, $\lambda_s$ is given by:

$$\lambda_s = \lambda_0 + \Omega_s - \Delta E t \qquad \text{(E-3)}$$

where $\Delta E = 7.292115856 \times 10^{-5}$ rad/s.

To complete a time description of the position of the sub-satellite point one needs to account for the position of the orbit as well as the position of the satellite on the orbit. The ascending node processes westward at a rate of 9.964 $(R_E / R_S)^{3.5} \cos I$ degrees per day, where $R_E$ (= 6378.14 km) is the equatorial radius of the Earth. Hence, the location of the ascending node evolves in time as:

$$\Omega_S = \Omega_0 - \Delta L t$$

where:

$\Delta L = -2.0183 \times 10^{-6} (R_E / R_S)^{3.5} \cos I$. Thus equation (E-3) becomes:

$$\lambda_S = \lambda_0 + \Omega_0 - (\Delta L + \Delta E)\, t \tag{E-4}$$

The orbital period (s) of a satellite in a circular orbit of radius $R_S$ is given by $T_S = 9.952004586 \times 10^{-3} R_S{}^{1.5}$, where $R_S$ is the radius of the satellite orbit (km). Therefore:

$$M = M_0 + \Delta M t \tag{E-5}$$

where $\Delta M = 2\pi / T_S$.

## E.4. Distance and azimuth to a terrestrial station

The position of the terrestrial station must first be converted from standard coordinates of latitude and longitude into spherical coordinates. If $L_T$ is the latitude and $Lo_T$ is the longitude of the terrestrial station, both positive angles (degrees), the spherical coordinates of the station (rad), $\theta_T$ and $\lambda_T$, may be obtained with the following two relations.

$$\theta_T = \begin{cases} (\pi/180)\,(90 - L_T) & \text{for } L_T \text{ North latitude} \\ (\pi/180)\,(90 + L_T) & \text{for } L_T \text{ South latitude} \end{cases} \tag{E-6}$$

$$\lambda_T = \begin{cases} (\pi/180)\,(Lo_T) & \text{for } Lo_T \text{ East longitude} \\ (\pi/180)\,(360 - Lo_T) & \text{for } Lo_T \text{ West longitude} \end{cases} \tag{E-7}$$

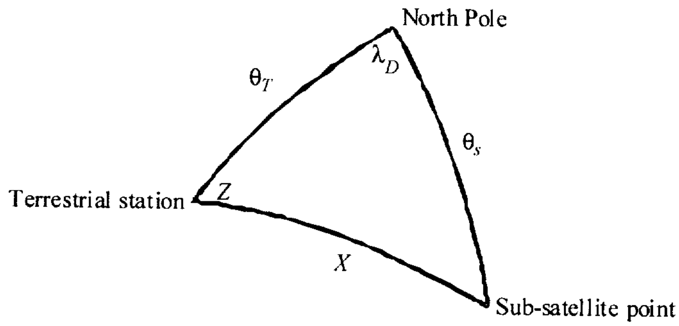
The difference in longitude from the terrestrial station to the sub-satellite point, $\lambda_D$, is just

$$\lambda_D = \lambda_S - \lambda_T \tag{E-8}$$

The distance $X$ between the terrestrial station and the sub-satellite point in radians of arc may be determined by the law of cosines, referring to Fig. 2, as:

$$X = \arccos\,(\cos\theta_T \cos\theta_S + \sin\theta_T \sin\theta_S \cos\lambda_D) \tag{E-9}$$

FIGURE 2
**Spherical triangle for the distance between the sub-satellite point and the terrestrial station**




The sub-satellite point is East of the terrestrial station if sin $\lambda_D$ is greater than zero and is West of the terrestrial station if sin $\lambda_D$ is less than zero. Hence the azimuth $Z$ from the station to the sub-satellite point is obtained by applying the law of cosines to the arc $\theta_S$ in Figure 2.

$$Z = \begin{cases} \arccos \dfrac{\cos\theta_S - \cos\theta_T \cos X}{\sin\theta_T \sin X} & \text{for } \sin\lambda_D \quad 0 \\ 2\pi - \arccos \dfrac{\cos\theta_S - \cos\theta_T \cos X}{\sin\theta_T \sin X} & \text{for } \sin\lambda_D \quad 0 \end{cases} \tag{E-10}$$

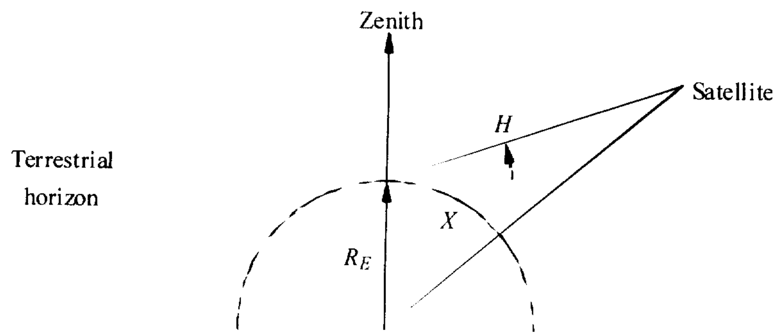
## E.5. Satellite elevation and angular distance from main beam

The elevation angle $H$ of the satellite above the horizon of the terrestrial station, assuming a horizon angle of 0°, may be obtained by referring to Figure 3.

$$H = \arctan \frac{\cos X - R_E / R_S}{\sin X} \tag{E-11}$$

FIGURE 3

**Plane containing Earth centre, terrestrial station, and satellite**

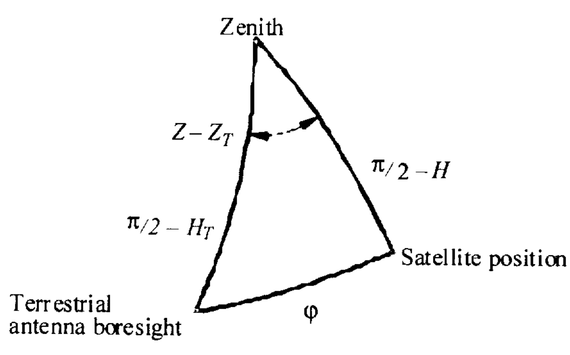



Assume that the receiving antenna of the terrestrial antenna is aimed along the azimuth $Z_T$ with an elevation angle of $H_T$ radians above the local horizontal. The angular distance φ from the main beam of this terrestrial station antenna to the satellite may be obtained by considering the spherical coordinate system centered on the terrestrial station with its axis in the zenith direction, as shown in Figure 4. Applying the law of cosines to the side φ gives:

$$\varphi = \arccos(\sin H_T \sin H + \cos H_T \cos H \cos(Z - Z_T)) \qquad \text{(E-12)}$$

FIGURE 4

**Spherical triangle for determination of the angle between the terrestrial beam and the satellite**




Equations (1) to (12) provide a means for simulating the interference environment of a terrestrial station in the presence of a low-Earth orbiting satellite. Some simplifications are possible. For instance, only interference from satellites above the horizon is usually considered. From equation (11), the satellite is above the horizon for:

$$\cos X > R_E / R_S = \gamma \qquad \text{(E-13)}$$

By using (13) in (9), it is possible to develop an expression for the range of longitudes that are within this circle of visibility for a particular sub-satellite point latitude or mean anomaly. Hence equations (10), (11) and (12) need only be evaluated under conditions that can be predetermined.

## Annex F: NSMA Frequency Coordination Process (Between MSS and FS Users in the band 2165-2200 MHz)

As an adjunct to the TIA Joint Working Group which developed the instant TIA Telecommunications Bulletin TSB-86, an Ad Hoc Committee on Procedures was created to get a head start and to begin to develop MSS/FS co-ordination procedures, while the full JWG focused on the technical aspects of sharing; i.e., interference criteria and methodologies for assessing the levels of interference from MSS downlink emissions into FS receive stations. It was contemplated from the start that the work of the Ad Hoc Committee would be further developed *after* a major part of the JWG work was completed and any final co-ordination procedures for MSS/FS sharing would be done in conjunction with the NSMA. This is much the same way as it developed and is now finalizing such a recommendation for PCS Coordination Procedures with FS users in the 1.9 GHz band.

The JWG is sponsored by TIA with the active participation of NSMA and both the MSS and FS industries. Within TIA, both the Satellite and Orbit Utilization (SOUS) Section of the Satellite Communications Division (SCD), and the Fixed Point-to-Point Communications Section of the Network Equipment Division (NED) oversee the work of the JWG, which is known as TR-34.2/TR-14.11. The genesis of the JWG came in response to the Federal Communications Commission's proceeding in ET Docket No.95-18, RM-7927, PP-28, concerned with "Amendment of Section 2.106 of the Commission's Rules to Allocate Spectrum at 2 GHz for use by the Mobile Satellite Service." In both the First Report and Order and in the Notice of Further Rulemaking in this proceeding, the Commission recognized the importance of the work underway in the JWG and indicated its intent to adopt the work of the JWG regarding interference criteria and sharing arrangements.

Given the reliance placed by the Commission on the work of the JWG, and given the expectation that the JWG will finalize a TSB to assess the interference potential between MSS and FS in the 2165-2200 MHz band, the MSS and FS industries concerned will also need coordination procedures that can be agreed to and implemented in practice. This need can best be served by the development and adoption of a *Methods and Procedures Recommendation for MSS Coordination Procedures with Fixed Microwave Users in the Band.*

## Annex G: Methodology To Be Used in Transforming PDF Data for the variable $I_{dBW}$ into PDF Data for the variable $I''_{dB}$

In order to apply the results of section 3.5, it is necessary to have PDF data for the variable $I''_{dB}$ which was defined as a variable that represents the fade margin loss in the FS system (expressed in dB). Typically, MSS providers will either provide PDF data for the variable $I_{dBW}$, where $I_{dBW}$ represents the level of interference power, in dBW, arriving from the MSS system at the input to the FS receiver system, or they will provide orbital and operational characteristics from which PDF data for the variable $I_{dBW}$ can be derived. In either case, a transformation must be made on the PDF data for $I_{dBW}$ in order to obtain the PDF data for $I''_{dB}$ that is necessary in the evaluation methodology of section 3.5. This appendix provides the derivation of the requiredtransformation. Specifically, a procedure is described that can be used to generate PDF data for a variable given a set of PDF data for a different but related random variable, which in our case are $I_{dBW}$ and $I''_{dB}$, respectively. The primary reference used in this analysis is *Probability, Random Variables, and Stochastic Processes* [Papoulis, 1965].

### G.1. General Transformation Equation

Assume there are two variables, X and Y, with the variable Y a function of X. To find the PDF of Y, $f_Y(y)$, for a given $y$ we solve the equation:

$$y = g(x) \tag{G-1}$$

for $x$ in terms of $y$. If $x_1, x_2, \ldots, x_n$ are all the real roots in solving the above equation, then the general form for transforming between the PDFs of X and Y is given by [Papoulis, 1965]:

$$f_y(y) = \frac{f_x(x_1)}{|g'(x_1)|} + \frac{f_x(x_2)}{|g'(x_2)|} + \ldots + \frac{f_x(x_n)}{|g'(x_n)|} \tag{G-2}$$

where

$$g'(x) = \frac{dg(x)}{dx} \tag{G- 3}$$

## G.2. Relationship Between $I''_{dB}$ and $I_{dBW}$

The relationship between the variables $I$ and $I''$ was originally defined in section 3.5 and is repeated below:

$$I'' = \frac{N + I}{N} \tag{G-4}$$

where

$I$ = A variable that represents the level of interference power, in Watts, arriving from the mobile satellite system (MSS) at the input to the fixed service (FS) receiver

$I''$ = A variable that represents the amount that the MSS interference power exceeds the noise floor, N, at the input to the FS receiver (expressed as a linear power ratio). $I''$ can be considered the threshold degradation.

We now consider the relationship between $I''_{dB}$ and $I_{dBW}$ where:

$I_{dBW}$ = A variable that represents the level of interference power, in dBW, arriving from the mobile satellite system (MSS) at the input to the fixed service (FS) receiver

$I''_{dB}$ = A variable that represents the amount that the MSS interference power exceeds the noise floor, N, at the input to the FS receiver (expressed in dB)

Using the relationships provided by Equation G-4 we can write:

$$I''_{dB} = 10\log\frac{10^{\left(\frac{I_{dBW}}{10}\right)} + N}{N} \qquad \text{(G-5)}$$

## G.3. Restatement of the Transformation Equation

Given the above relationship between $I''_{dB}$ and $I_{dBW}$, we can develop an equivalent set of expressions to those provided in [Papoulis, 1965]. That is, we can state that:

$$\begin{array}{cc} X \quad I_{dBW}; x & i_{dBW} \\ Y \quad I''_{dB}; y & i''_{dB} \\ x_1, x_2, \ldots, x_n & i_{1,dBW}, i_{2,dBW}, \ldots, i_{n,dBW} \end{array} \qquad \text{(G-6)}$$

and

$$f_{I''_{dB}}(i''_{dB}) = \frac{f_{I_{dBW}}(i_{dBW} = i_{1,dBW})}{|g'(i_{1,dBW})|} + \frac{f_{I_{dBW}}(i_{dBW} = i_{2,dBW})}{|g'(i_{2,dBW})|} + \ldots + \frac{f_{I_{dBW}}(i_{dBW} = i_{n,dBW})}{|g'(i_{n,dBW})|} \qquad \text{(G-7)}$$

## G.4. Application of the PDF Transformation

Noting the relationship between $I''_{dB}$ and $I_{dBW}$ as defined by Equation G-5 above, (i.e., $I''_{dB} = g(I_{dBW})$), and applying Equations G-1 and G-2, we must solve the following equation for $i_{dBW}$ in terms of $i''_{dB}$:

$$i''_{dB} = g(i_{dBW}) = 10\log\frac{10^{\left(\frac{i_{dBW}}{10}\right)} + N}{N} \qquad \text{(G-8)}$$

The result is a single root for all $i_{dBW}$:

$$i_{dBW} = 10\log\ (N)\left\{10^{\frac{i''_{dB}}{10}}\right\} \quad N \qquad\qquad i_{1,dBW} \tag{G-9}$$

Next, we calculate $g'(i_{1,dBW})$ which is simply $g'(I_{dBW} = i_{1,dBW})$. The following derivative relationships will be useful in calculating $g'(i_{1,dBW})$ and are from [Beyer, 1981]:

$$\frac{d(au)}{dx} \ . \ a\frac{du}{dx} \quad \text{with "a" a constant}$$

$$\frac{d(\log_a u)}{dx} \ . \ (\log_a e)\left(\frac{1}{u}\right)\frac{du}{dx} \tag{G-10}$$

$$\frac{d(a^u)}{dx} \ . \ a^u(\log_e a)\frac{du}{dx}$$

Applying the above relationships to Equation G-8, we obtain:

$$g'(I_{dBW}) = 10(\log_{10} e)\left(\frac{N}{10^{\frac{I_{dBW}}{10}} + N}\right)\left(\frac{du}{dI_{dBW}}\right) \tag{G-11}$$

where $u$ is:

$$\frac{10^{\left(\frac{I_{dBW}}{10}\right)} \ . \ N}{N} \tag{G-12}$$

and $du/dI_{dBW}$ *is:*

$$\left(\frac{1}{N}\right)\left(10^{\frac{I_{dBW}}{10}}\right)(\log_e 10)\left(\frac{1}{10}\right) \tag{G-13}$$

Combining Equations G-11 and G-13 and simplifying we obtain:

$$g''(I_{dBW}) = \frac{1}{1+N\left(10^{\frac{-I_{dBW}}{10}}\right)} \qquad \text{(G-14)}$$

Using Equation G-9 for the value of $i_{1,dBW}$ and substituting into Equation G-14 above, we calculate the following expression for $g'(I_{dBW} = i_{1,dBW})$ after some algebraic manipulation:

$$g'(I_{dBW} = i_{1,dBW}) = 1 - 10^{\frac{-i''_{dB}}{10}} \qquad \text{(G-15)}$$

Finally, substituting the results of Equation G-9 and G-15 into Equation G-7 above, we obtain the following transformation between the PDFs of the variables $I_{dBW}$ and $I''_{dB}$:

$$f_{I''_{dB}}(i''_{dB}) \quad \frac{f_{I_{dBW}}(i_{dBW} = i_{1,dBW})}{|g'(i_{1,dBW})|}$$

$$\frac{f_{I_{dBW}} \; i_{dBW} \quad 10\log \; N10^{\frac{i''_{dB}}{10}} \quad N}{1 \quad 10^{\frac{-i''_{dB}}{10}}} \qquad ; \qquad i''_{dB} \quad 0\,dB \qquad \text{(G-16)}$$

$$0 \qquad ; \qquad i''_{dB} \quad dB$$

## G.5. Example Calculation

Assume that we have PDF data for the variable $I_{dBW}$, the level of the MSS interference power present at the input to the FS receiver, in dBW, and we want to determine the PDF of $I''_{dB}$, the level, in dB, that the MSS interference power at the input to the FS receiver exceeds the noise floor, N, at a particular value, $i''_{dB} = 2$ dB. As seen in Equation G-16, the transformation is a function of the noise floor value.

Let us assume that the noise floor of the FS receiver is –140 dBW or $10^{-14}$ Watts. Applying Equation G-16, we calculate the following:

$$f_{I''_{dB}}(i''_{dB} \quad 2dB) \quad \frac{f_{I_{dBW}} \quad i_{dBW} \quad 10\log\,(10^{-14})(10^{\frac{2}{10}}) \quad 10^{-14}}{1 \quad 10^{\frac{-2}{10}}}$$

$$(2.71) f_{I_{dBW}}(i_{dBW} \quad 142.36dBW) \tag{G-17}$$

As shown, the transformation results in a scaling factor and a non-linear shift along the x-axis.